A black and white photograph of an ATR 42-500 regional jet in flight. The aircraft is angled upwards towards the top right of the frame. The registration "OK-KFO" is visible on the rear fuselage. The background is a clear sky.

“The engineers had the firm belief that the hybrid was the answer to all these questions -- oil depletion, emissions, and the long-term future of the automobile society -- but the business people weren't in agreement.”



8,000,000

Worldwide Sales of Toyota Hybrids as of July 2015



Mission Analysis and Aircraft Sizing of a Hybrid-Electric Regional Aircraft

Kevin R. Antcliff
NASA Langley
Research Center

Co-Authors:

Mark D. Guynn, Ty V. Marien, Douglas P. Wells
NASA Langley Research Center
Steven J. Schneider, Michael T. Tong
NASA Glenn Research Center

Background Credit: Sefjo, available at https://commons.wikimedia.org/wiki/File:Czech_Airlines_ATR_42-500_OK-KFO.jpg, licensed under CC BY-SA 3.0.

AIAA SciTech 2016, January 4-8, 2016
San Diego, California

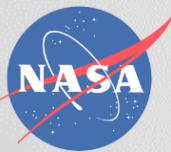


Outline

1. Background & Introduction
2. Approach
3. Results
4. Conclusions
5. Future Work



1. Background & Introduction



Short Haul Revitalization Study

MOBILITY THROUGH THE AIR IS VITAL TO ECONOMIC STABILITY, GROWTH, AND SECURITY AS A NATION

National Plan for Aeronautics R&D and Related Infrastructure

U.S. leadership for a new era of flight

6 Strategic Thrusts



Safe, Efficient Growth
in Global Operations



Innovation in Commercial
Supersonic Aircraft



Ultra-Efficient
Commercial Vehicles



Transition to
Low-Carbon Propulsion



Real-Time System-Wide
Safety Assurance



Assured Autonomy for
Aviation Transformation



nasa.gov



Many Experimental Aircraft... ...Even More to Come



nasa.gov



nasa.gov



Background Credit: Sefjo, available at https://commons.wikimedia.org/wiki/File:Czech_Airlines_ATR_42-500_OK-KFO.jpg, licensed under CC BY-SA 3.0.



Objective

- Would a parallel hybrid-electric aircraft introduced in the 2030 time frame be competitive with conventional aircraft for a regional, short-haul mission?

Output

- Total energy consumption
- Total projected energy cost
- TOGW, OEW, Battery Weight, etc.





2. Approach

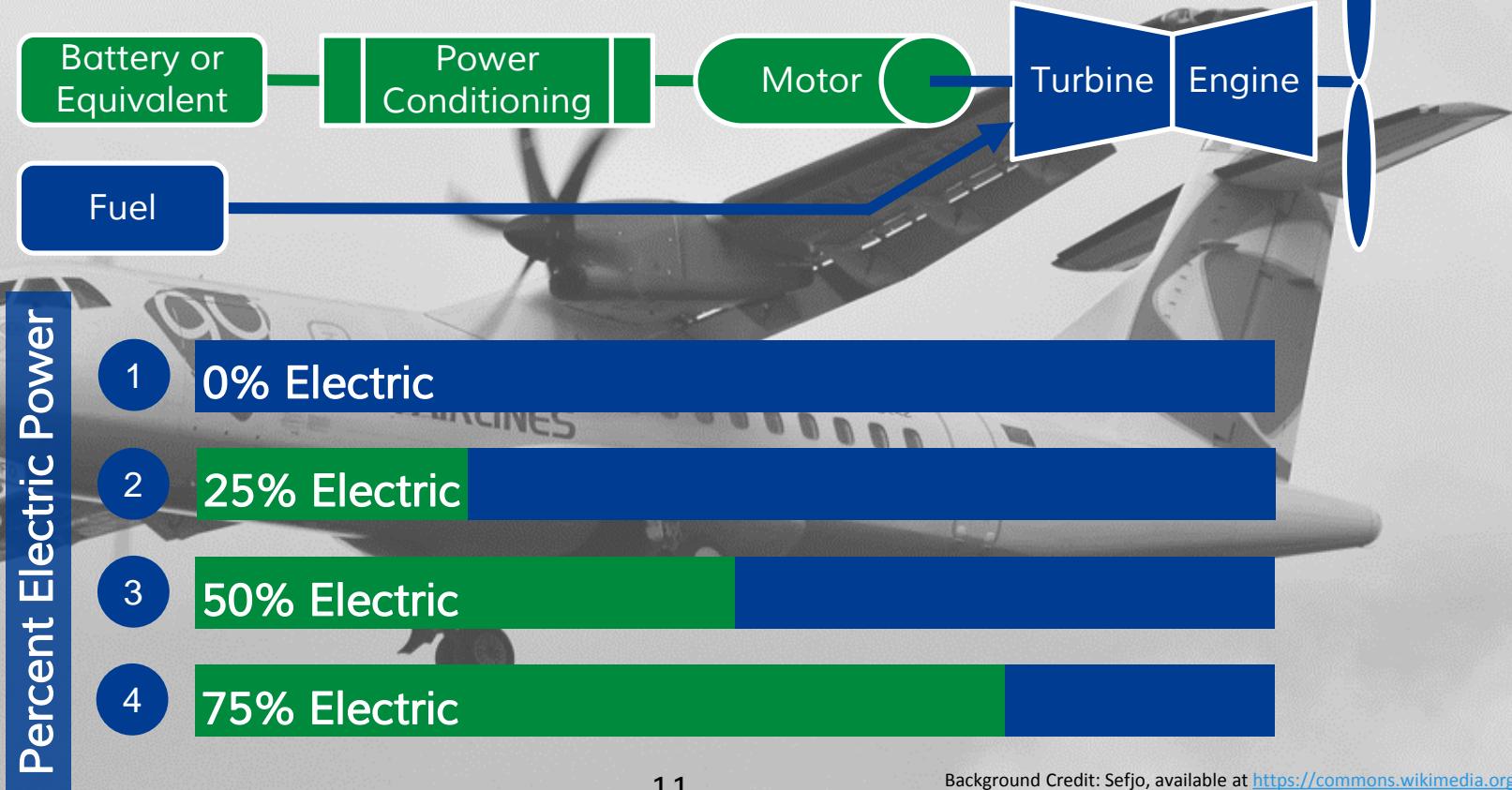


Study Decisions and Assumptions

- Year 2030 technology
- Parallel hybrid-electric propulsion
- Various levels of battery specific energy
- No deviation from propulsion airframe integration of baseline aircraft
- No change to airframe design parameters
- Fixed level of electrification for full mission
- Tools used include: OpenVSP, FLOPS, NPSS, WATE++, and ModelCenter



Parallel Hybrid-Electric Propulsion and Percent Electrification





Baseline Aircraft

ATR 42-500

48 pax

840 nm

Mach 0.475

5% Reserve

87 nm Alternate Airport

45 min. hold

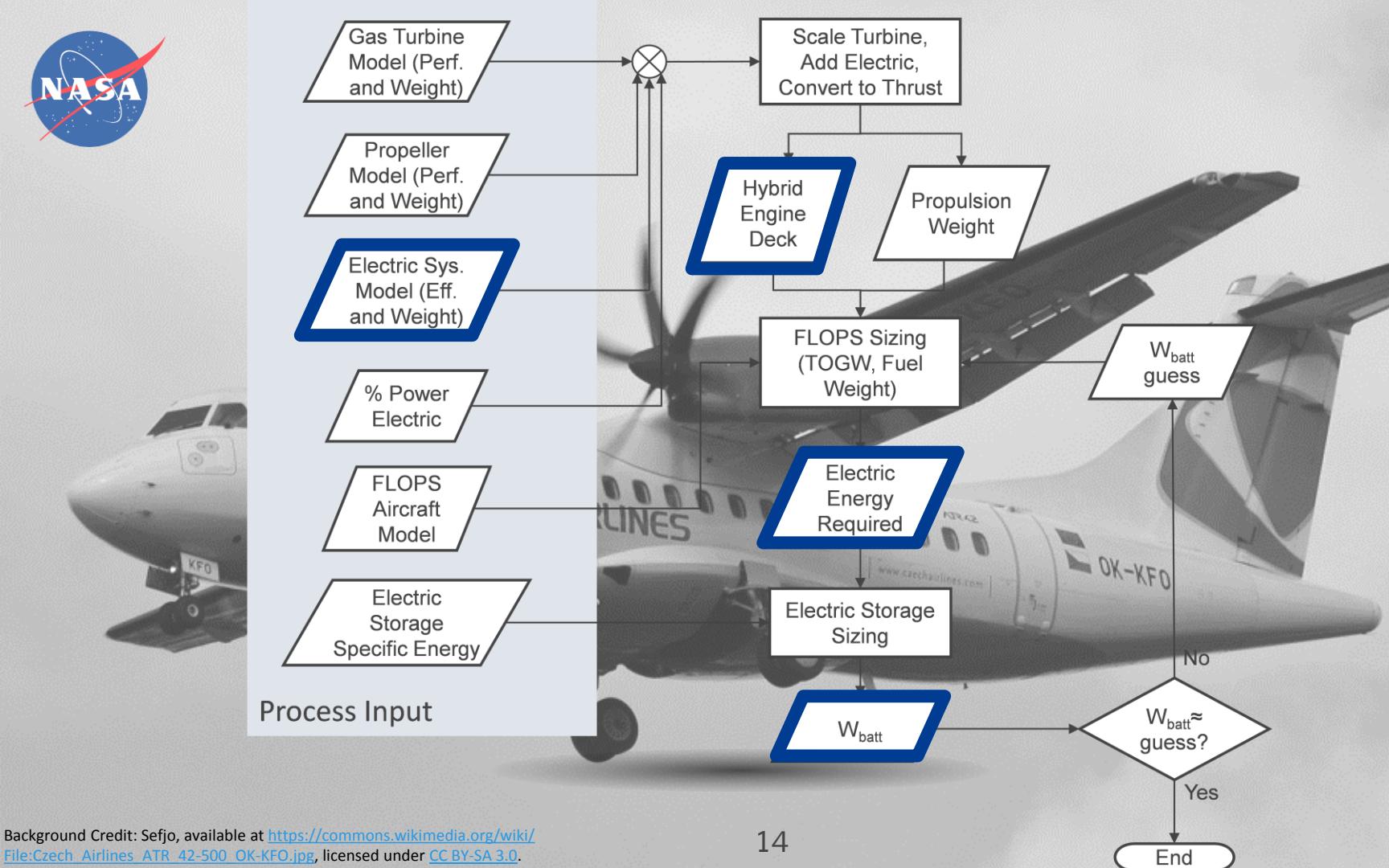
Ty V. Marien.
Seat Capacity
Selection for
an Advanced
Short-Haul
Aircraft Design
3:30 – 4:00pm
Today



Advanced Aircraft (Year 2030)

- 
- A large, semi-transparent 3D rendering of an aircraft is positioned on the left side of the slide. The aircraft is shown from a front-three-quarter perspective, featuring a grey fuselage, a white vertical stabilizer with a NASA logo, and a dark grey wing with a propeller at the front. The background of the slide is a solid blue.
1. Baseline aircraft modeled
 2. Calibrated to match ATR 42-500
 3. Decreased to the study mission range of 600 nm
 4. Advanced technology factors introduced
 5. Advanced aircraft sized for minimum gross weight to meet study mission
 6. Hybrid-electric engine deck introduced
 7. Optimized with hybrid-electric propulsion and additional battery weight

Multi-Disciplinary Optimization Framework





3. Results



Modified NASA PW127E-like Performance: Current and Advanced

	Units	2015	2030
Mach		0	0
Altitude	ft	0	0
Throttle	%	100	100
Power	hp	2,400	2,400
Jet Thrust	lbf	287	287
SFC	lbm/hr/hp	0.474	0.427
Mass Flow	lbm/s	12.15	10.65
OPR		14.7	14.7



Modified NASA PW127E-like Weights: Current and Advanced

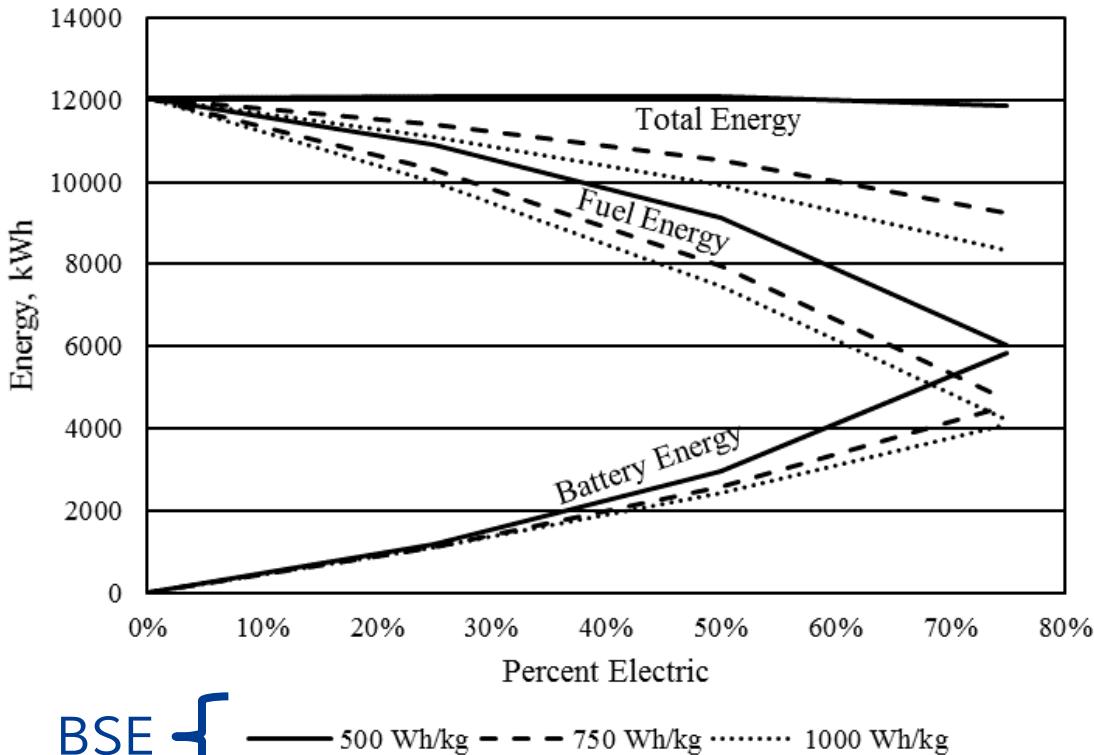
Component Weights (lb)	Current 2400 SHP	Advanced 2400 SHP	Advanced Hybrid-Electric Gas Turbine + Electric Motor		
			1800 + 600 SHP	1200 + 1200 SHP	600 + 1800 SHP
Turbine Engine + Gearbox	1054	1010	819	626	410
Propeller System + Nacelle	782	781	766	752	737
Electrical System	-	-	135	270	405
Total System	1836	1791	1720	1648	1552



Study Cases at 600 nm

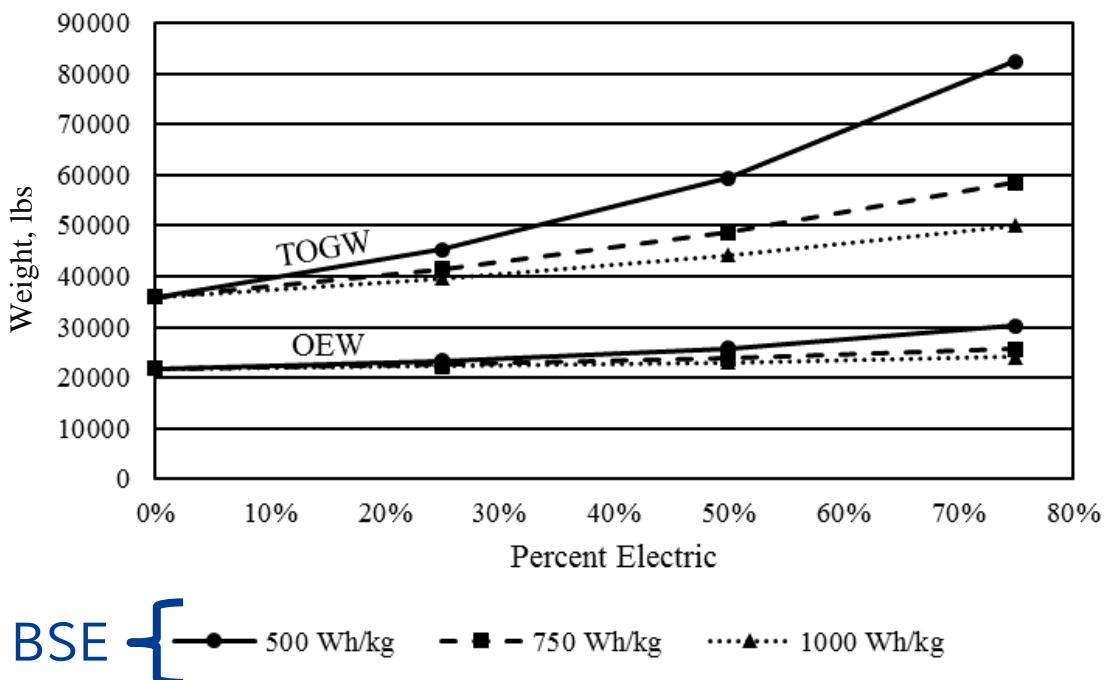
Percent Electric	Battery Specific Energy
0%	500 Wh/kg
25%	750 Wh/kg
50%	1000 Wh/kg
75%	

Battery Specific Energy = BSE in the following slides



Battery, Fuel, and Total Energy versus Percent Electric

- Battery energy and fuel energy are equal at 76% electric
 - At 500 Wh/kg, total energy remains relatively constant
 - At 750 and 1000 Wh/kg, the total energy decreases significantly



TOGW and OEW versus Percent Electric

Comparing our advanced 75% electric to 0% electric:

At 500 Wh/kg:

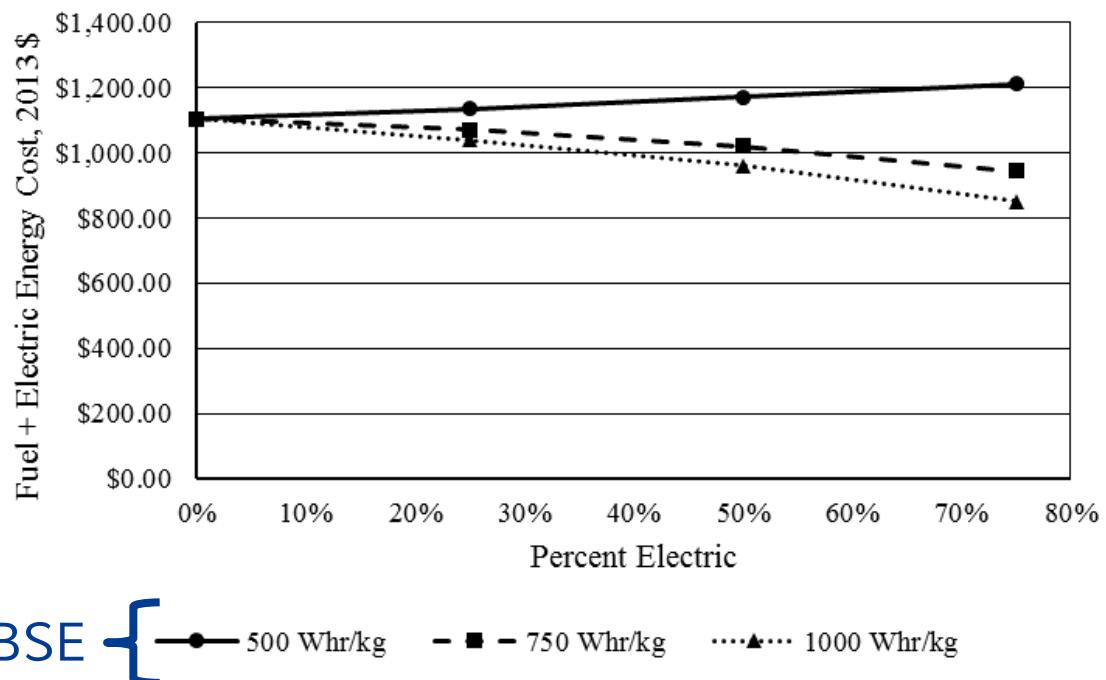
- 2.3X heavier TOGW

At 750 Wh/kg:

- 63% heavier TOGW

At 1000 Wh/kg:

- 39% heavier TOGW



Total Energy Cost verus Percent Electric

- \$3.33 per gallon for Jet-A
 - \$0.11 per kWh for elec.
- Comparing advanced 75% electric to 0% elec.

At 500 Wh/kg:

- 10% more

At 750 Wh/kg:

- 14% less

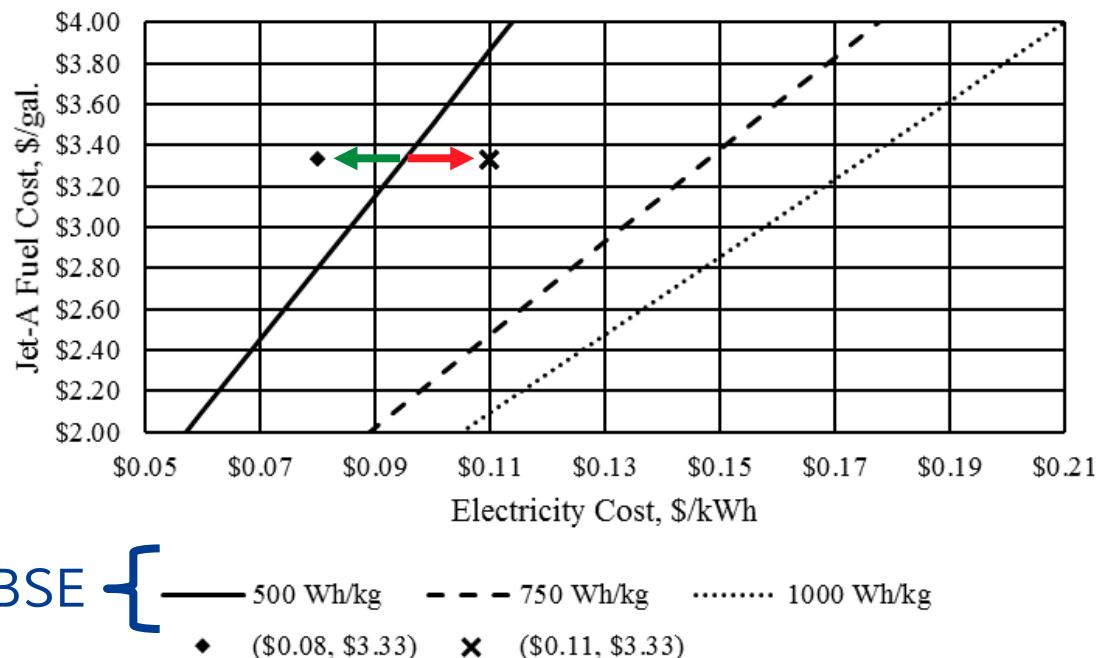
At 1000 Wh/kg:

- 23% less



Design Range Sensitivity (500 Wh/kg)

%Electric	Units	0%	75%	0%	75%
Range	nm	300	300	600	600
Total Fuel Weight	lb	2,310	850	3,340	1,720
Total Batt. Weight	lb	0	15,270	0	39,590
OEW	lb	21,300	24,200	21,800	30,300
TOGW	lb	34,500	51,100	35,900	82,400
Elec. Energy Cost	\$	0	260	0	660
Fuel Energy Cost	\$	610	220	1,110	550
Total Energy Cost	\$	610	480	1,100	1,210



Break-Even Energy Cost for the 75% Electric Advanced Turboprop

Prediction 1:

- \$3.33 per gallon of Jet-A
- \$0.11 per kWh for elec.
- 9% increase in total energy cost →

Prediction 2:

- \$3.33 per gallon of Jet-A
- \$0.08 per kWh for elec.
- 14% decrease in total energy cost ←



4. Conclusions



Conclusions

- At 600 nm, BSE must be greater than 500 Wh/kg to yield energy consumption parity
- At 300 nm, BSE can be less than 500 Wh/kg for energy consumption parity
- The economics for a parallel hybrid vehicle at 600 nm and 500 Wh/kg is less attractive than for a conventional unless the electricity to fuel cost ratio decreases
- The 75% electric advanced turboprop needs a BSE of 600 Wh/kg to operate in total energy cost parity

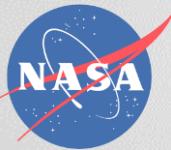


5. Future Work



Future Work

- Explore additional comparison metrics (life cycle emissions, noise, etc.) for hybrid and conventional aircraft
- Determining the BSE needed at a given design range to achieve a given objective
- Alternative propulsion-airframe integration that takes advantage of additional flexibilities provided by electric propulsion (distributed electric propulsion, series-hybrid, etc.)
- Optimize additional airframe design parameters to ensure a match between airframe and propulsion



Thanks!

Any questions?

Acknowledgements:

This work was funded by NASA's Advanced Air Transport Technologies project.